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PERFORMANCE OF A CLASS 1 BARREL-STAVE FLEXTENSIONAL TRANSDUCER DRIVEN BY A NAVY TYPE V INTEGRATED ACTUATOR

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Defence R&D Canada

DEFENCE RESEARCH ESTABLISHMENT ATLANTIC

Technical Memorandum

DREA TM 2000-135

November 2000

National Defence Défense nationale

Canada

Copy No: _____

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102-01456/

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Abstract

An SX100 barrel-stave flextensional transducer driven by a Navy Type V piezoceramic integrated actuator was manufactured by Sensor Technology Limited and tested in 30.0 meters of seawater at the DREA Acoustic Calibration Facility. This miniature sonar transducer resonates at 1.46 kHz and produces a sound pressure level of 193.7 dB//1μPa-m when driven with an electric field of 2.4 kVrms/cm. This is a 5.9 dB improvement over an SX100 transducer driven with a Navy Type I driver with the same field. The mass figure of merit of the Navy Type V is 36 W/kg-kHz-Q.

Résumé

Un transducteur flextensionnel à douves commandé par un dispositif intégré piézocéramique naval de type V a été fabriqué par Sensor Technology Limited et mis à l'essai dans 30,0 mètres d'eau de mer à l'installation d'étalonnage acoustique du CRDA. Ce transducteur de sonar miniature résonne à 1,46 kHz et produit un niveau de pression sonore de 193,7 dB//1μPa-m lorsqu'il est excité par un champ électrique de 2,4 kVeff./cm. Il s'agit là d'une amélioration de 5,9 dB par rapport au transducteur SX100 excité par un dispositif de commande naval de type I avec le même champ. Le facteur de qualité de masse du dispositif naval de type V est de 36 W/kg-kHz-Q.

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Executive summary

The SX100 barrel-stave flextensional transducer is a miniature underwater sound source that was developed jointly by DREA and Sensor Technology Limited for expendable naval sonar applications. Recently, Sensor Technology adapted their proprietary actuator manufacturing processes to produce integrated actuator drivers (IADs) for the SX100 transducer. The advantage of using an IAD over a conventional stack driver is a significant reduction in cost per transducer. Today, all Sensor Technology barrel-stave transducers use these actuator drivers.

Most high power sonar transducers use piezoceramic drivers made from either Navy Types I or III elements. One of the reasons for this is that these ceramic formulations have low electrical dissipation factors, resulting in good electroacoustic efficiencies and low temperature rises for high duty cycle operation. When designing for expendable applications, where the lifetime of the transducer is measured in seconds or minutes, higher dissipation factors may be acceptable if higher sound pressure levels are a priority.

Sensor Technology manufactures a piezoelectric Navy Type V ceramic that has a larger electrical dissipation factor than Navy Type I or III, but at the same time has a significantly larger piezoelectric charge constant. This means that, for a given applied electric field, the SX100 with a Type V driver can produce more sound pressure level than the same transducer with a Type I driver.

In order to assess this assertion, an experimental SX100 transducer with a Navy Type V integrated actuator driver was constructed by Sensor Technology and sent to DREA for in-water testing. The measured performance parameters are compared to those of an SX100 transducer driven with a Navy Type I driver.

At its 1.46 kHz fundamental flexural resonance, the Navy Type V SX100 barrel-stave transducer produces a sound pressure level of 193.7 dB//1μPa-m when driven with an electric field of 2.4 kVrms/cm. This is a 5.9 dB improvement over the Navy Type I transducer driven with the same field.

Jones, D.F., Reithmeier, C.G. 2000. Performance of a Class I barrel-stave flextensional transducer driven by a Navy Type V integrated actuator. DREA TM 2000-135 Defence Research Establishment Atlantic.

Sommaire

Le transducteur flextensionnel à douves SX100 est une source sonore sous-marine miniature qui a été mise au point conjointement par le CRDA et Sensor Technology Limited pour des applications de sonar naval dépensables. Récemment, Sensor Technology a adapté ses procédés exclusifs de fabrication de dispositifs de commande afin de produire des dispositifs de commande intégrés (IAD) pour le transducteur SX100. Par rapport à une chaîne classique, l'IAD a l'avantage de coûter sensiblement moins cher par transducteur. Aujourd'hui, tous les transducteurs à douves de Sensor Technology utilisent ces dispositifs de commande.

La plupart des transducteurs de sonar à grande puissance utilisent des dispositifs de commande piézocéramiques composés d'éléments navals de type I ou III, entre autres parce que ces préparations céramiques ont de faibles facteurs de dissipation électrique, ce qui permet de bons rendements électroacoustiques et de faibles augmentations de température pour un facteur d'utilisation élevé. Dans la conception d'applications dépensables, où la durée de vie du transducteur est mesurée en secondes ou en minutes, on peut accepter des facteurs de dissipation élevés si des niveaux de pression sonores élevés sont prioritaires.

Sensor Technology fabrique une céramique piézoélectrique navale de typeV présentant un facteur de dissipation électrique supérieur à celui de type I ou III, mais ayant en même temps une constante de charge piézoélectrique nettement plus grande. Cela signifie que, pour un champ électrique appliqué donné, le SX100 avec dispositif de commande de type V produit un niveau de pression sonore supérieur à celui du même transducteur utilisé avec un dispositif de commande de type I.

Afin d'évaluer cette assertion, un transducteur SX100 expérimental avec dispositif de commande intégré naval de type V a été construit par Sensor Technology et envoyé au CRDA pour être mis à l'essai dans l'eau. Les paramètres de performance mesurés sont comparés à ceux d'un transducteur SX100 commandé par un dispositif de commande naval de type I.

À sa fréquence fondamentale de résonance en flexion de 1,46 kHz, le transducteur à douves SX100 naval de type V produit un niveau de pression sonore de 193,7 dB//1µPa-m lorsqu'il est excité par un champ électrique de 2,4 kVeff./cm. Il s'agit là d'une amélioration de 5,9 dB par rapport au transducteur naval de type I excité par le même champ.

Jones, D F., Reithmeier, C.G. 2000. Performance of a Class I barrel-stave flextensional transducer driven by a Navy Type V integrated actuator. DREA TM 2000-135 Centre de recherches pour la défense, Atlantique.

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Acknowledgements

The authors would like to thank David Lewis and Dave Doucette for their assistance at the DREA Acoustic Calibration Barge. We are also grateful to the SX100 team at Sensor Technology for building the Navy Type V barrel-stave under their Defence Industrial Research Contract Number W2207-9-EA02/001/SV.

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1. Introduction

Class I barrel-stave flextensional transducers are low frequency underwater sound sources that are being developed by DREA for naval sonar applications. The reader is referred to Jones et al. [1, 2] and the references therein for background information.

The miniature SX100 Class I barrel-stave transducer, manufactured by Sensor Technology Limited, was designed at DREA for expendable applications. Its acoustic performance when driven with a Navy Type I integrated actuator driver (IAD) was reported by Jones [3]. Sensor Technology also has a commercial Navy Type V piezoceramic with a high piezoelectric charge constant and high coupling coefficient. These material properties can lead to a significantly improved sound pressure level.

In this paper, a Navy Type V IAD was installed in an SX100 by Sensor Technology and tested in seawater at DREA. The performance results are compared to a Navy Type I IAD SX100.

2. Transducer Description

The construction of a Class I SX100 barrel-stave flextensional transducer driven with a conventional Navy Type I piezoceramic stack can be found in Jones [4]. Basically, the transducer has a radiating shell consisting of six curved aluminum staves and two hexagonal end plates, which are excited by the internal stack. This miniature transducer has a 5.7 cm outside diameter, is 12.7 cm long, and has a mass of 1.1 kg.

A Navy Type V integrated actuator driver was installed in an SX100 transducer by Sensor Technology and shipped to DREA for testing. The piezoceramic actuator is 10.2 cm long and is electrically insulated at each end by machinable glass ceramic shims.

3. Material Properties

Table 1 compares Sensor Technology's published material properties for BM400 Navy Type I and BM532 Navy Type V piezoelectric ceramics [5]. The relative dielectric constant K^T_{33} and the dissipation factor *DF* for BM532 are higher than those for BM400, while the coupling coefficients k_{33} are the same. The piezoelectric charge constant d_{33} for BM532 is a factor of 2 higher than that for BM400, so for a given electric field, the former material will generate greater axial strain, causing the transducer to generate more sound pressure level. BM532 also has a higher compliance s^E_{33} than BM400, which will reduce the resonance frequencies of the SX100 transducer.

Using the same metrics described in Reference 2, the material properties in Table 1 can provide an estimate of the improvement in sound pressure level expected for an SX100 transducer driven with the Navy Type V material versus Navy Type I material. The comparison is summarised in Table 2. For an electric field of 2.4 kVrms/cm, the SX100 transducer driven by the Navy Type V IAD should produce about 4.9 dB more sound pressure level than the Navy Type V transducer.

Table 1. Material properties for Sensor Technology piezoceramics.

Material	K^T_{33}	*DF*	k_{33}	d_{33}	s^E_{33}
		(%)		*(pm/V)*	*(pm^2/N)*
BM400 Navy Type I	1350	0.4	0.68	285	15.0
BM532 Navy Type V	3250	2.0	0.68	580	20.0

Table 2. Calculated sound pressure level improvement.

MATERIAL	ELECTRIC FIELD	YOUNG'S MODULUS	STRAIN	ENERGY DENSITY	RELATIVE SPL
	(kVrms/cm)	*(GPa)*	*(ppm)*	*(J/m^3)*	*(dB)*
BM400 Navy Type I	2.4	67	97	315	0
BM532 Navy Type V	2.4	50	197	970	4.9

4. Acoustic Performance

The transmitting voltage response (TVR) of the Navy Type V SX100 barrel-stave flextensional transducer was measured at the DREA Acoustic Calibration Facility on Bedford Basin at a water depth of 30.0 m. An electric field of 420 Vrms/cm was applied to the transducer for this measurement. The TVR curve is shown in Figure 1. Also shown in the figure is the TVR curve for a Navy Type I SX100 transducer driven at 180 Vrms/cm in 30.0 m of water (data from Reference 3). The frequencies and TVR values of the three resonance peaks are listed in Table 3.

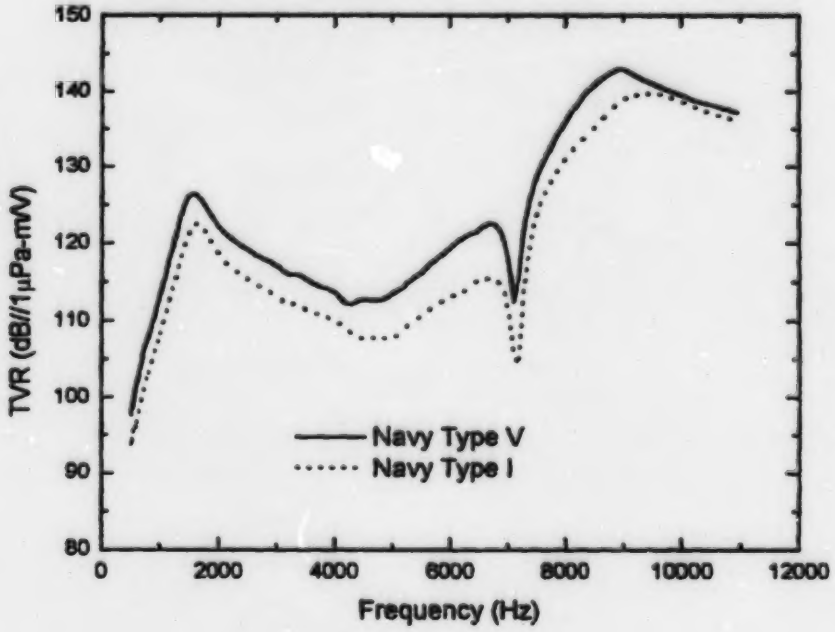

Figure 1. Transmitting voltage response.

Table 3. Maxima in the TVR curves in Figure 1.

RESONANCE	NAVY TYPE I		NAVY TYPE V	
	Frequency (kHz)	*TVR (dB//1μPa-m/V)*	*Frequency (kHz)*	*TVR (dB//1μPa-m/V)*
Fundamental flexural	1.63	122.6	1.57	126.4
Second flexural	6.84	115.4	6.69	122.6
Longitudinal	9.44	139.9	8.95	143.0

Shown in Figure 2 are the sound pressure levels (SPLs) for the Navy Type I and V SX100 transducers near their fundamental flexural resonances when driven in 30.0 m of water. An electric field of 2.4 kVrms/cm was applied to both transducers. The resonance frequency, SPL at resonance, and –3 dB bandwidth for the Navy Type V transducer are 1.46 kHz, 193.7 dB//1μPa-m, and 430 Hz. The same quantities for the Navy Type I transducer are 1.57 kHz, 187.8 dB//1μPa-m, and 490 Hz. These parameters are summarised in Table 4.

The SPL for the Navy Type V SX100 transducer in Figure 2 is repeated in Figure 3, but this time it is compared to the SPL of the Navy Type I transducer driven with an electric field of 3.9 kVrms/cm at 30.0 m water depth. Neither transducer was driven with higher fields in order to avoid the acoustic performance degradation effects associated with cavitation. For the SX100 transducer operating at 30.0 m depth, the cavitation threshold is estimated to be about 197 dB [6, 7]. The performance parameters for both transducers are summarised in Table 5.

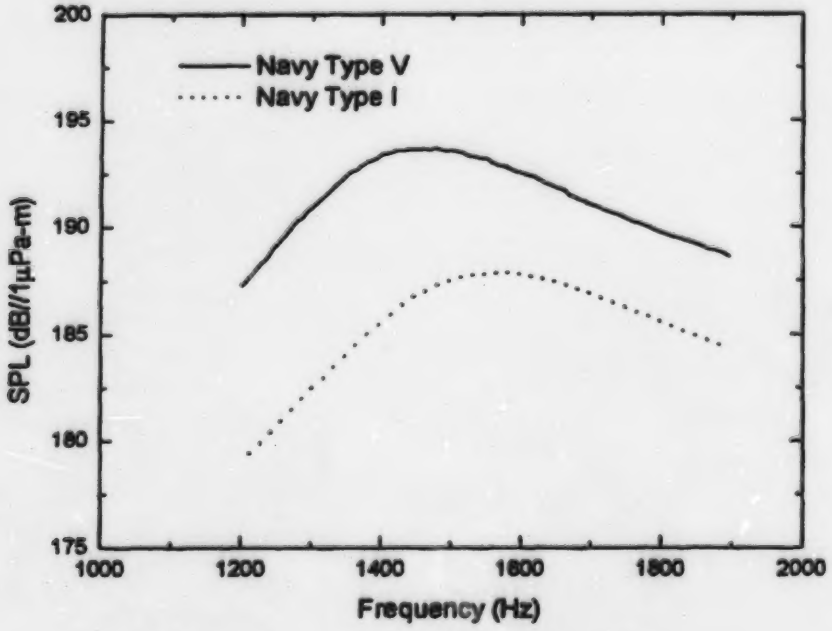

Figure 2. Sound pressure levels at 2.4 kVrms/cm.

Table 4. Parameters at the fundamental flexural resonances with the same drive field.

TRANSDUCER	FREQUENCY	SPL	FIELD	Q	BW
	(kHz)	(dB//1μPa-m)	(kVrms/cm)	(- 3 dB)	(- 3 dB)
Navy Type I SX100	1.57	187.8	2.4	3.2	490
Navy Type V SX100	1.46	193.7	2.4	3.4	430

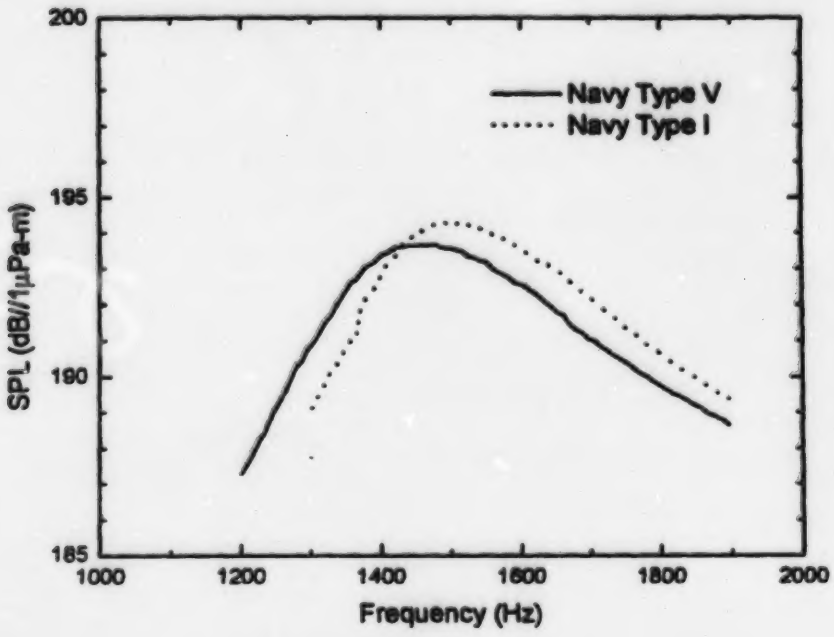

Figure 3. High field sound pressure levels measured in 30 m of water.

Table 5. High field parameters at the fundamental flexural resonances.

TRANSDUCER	FREQUENCY	SPL	FIELD	Q	FOM[1]
	(kHz)	*(dB//1µPa-m)*	*(kV/m/cm)*	*(- 3 dB)*	*(W/kg-kHz-Q)*
Navy Type I SX100	1.50	194 3	3.9	3.8	36
Navy Type V SX100	1.46	193.7	2.4	3.4	36

[1]The mass figure of merit (FOM) metric is discussed in Reference 2.

5. Discussion

Since the piezoelectric charge constant of BM532 Navy Type V piezoceramic is larger than that of BM400 Navy Type I piezoceramic (see Table 1), the TVR curve of the former has higher values throughout the frequency band below 10 kHz (see Figure 1). In addition, the larger elastic compliance constant of BM532 (see Table 1) leads to lower resonance frequencies for both the fundamental flexural and longitudinal modes (see Table 3). The effects of compliance on the second flexural mode cannot be ascertained since the actual resonance frequency of this mode is influenced by the strong longitudinal resonance.

The improvement in sound pressure level and the shift in resonance frequency obtained with the Navy Type V transducer can be quantified by driving the two transducers with the same electric field. The results for a 2.4 kVrms/cm field are shown in Figure 2 and listed in Table 4. The resonance frequency dropped from 1.57 kHz for the Navy Type I transducer to 1.46 kHz for the Navy Type V transducer; a decrease of 110 Hz. At the same time, the SPL increased by 5.9 dB from 187.8 dB//1μPa-m to 193.7 dB//1μPa-m. This is better than the 4.9 dB predicted from the book value material properties in Table 2.

As the data in Figure 3 and Table 5 indicate, both transducers are capable of generating source levels of about 194 dB//1μPa-m. The SX100 with the Navy Type V driver does so, however, with a low driving field of 2.4 kVrms/cm. Further testing of the Navy Type V transducer in deeper water (to avoid cavitation) and at higher drive levels should determine the field limited power capability of this transducer. Higher sound pressure levels would further increase an already good figure of merit.

6. Conclusions

An SX100 barrel-stave flextensional transducer driven by a Navy Type V piezoceramic integrated actuator was tested in 30.0 meters of seawater at the DREA Acoustic Calibration Facility. The flexural resonance frequency was 1.46 kHz and a 193.7 dB//1μPa-m sound pressure level was produced when an electric field of 2.4 kVrms/cm was applied. This is a 5.9 dB improvement over an SX100 transducer driven with a Navy Type I driver. The mass figure of merit of the Navy Type V transducer is 36 W/kg-kHz-Q.

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3 TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title)

Performance of a Class I barrel-stave flextensional transducer driven by a Navy Type V integrated actuator

4 AUTHORS (Last name, first name, middle initial If military, show rank, e.g Doe, Maj John E)

Dennis F. Jones and Charles G. Reithmeier

5 DATE OF PUBLICATION (month and year of publication of document)	6a NO OF PAGES (total containing information Include Annexes, Appendices, etc)	6b NO OF REFS (total cited in document)
November 2000	19	7

7 DESCRIPTIVE NOTES (the category of the document, e g technical report, technical note or memorandum If appropriate, enter the type of report, e g interim, progress, summary, annual or final Give the inclusive dates when a specific reporting period is covered)

TECHNICAL MEMORANDUM

8 SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development Include address)

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9a PROJECT OR GRANT NO (if appropriate, the applicable research and development project or grant number under which the document was written Please specify whether project or grant)	9b CONTRACT NO (if appropriate, the applicable number under which the document was written)
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10a ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity This number must be unique to this document)	10b OTHER DOCUMENT NOs (Any other numbers which may be assigned this document either by the originator or by the sponsor)
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An SX100 barrel-stave flextensional transducer driven by a Navy Type V piezoceramic integrated actuator was manufactured by Sensor Technology Limited and tested in 30.0 meters of seawater at the DREA Acoustic Calibration Facility. This miniature sonar transducer resonates at 1.46 kHz and produces a sound pressure level of 193.7 dB//1μPa-m when driven with an electric field of 2.4 kVrms/cm. This is a 5.9 dB improvement over an SX100 transducer driven with a Navy Type I driver with the same field. The mass figure of merit of the Navy Type V is 36 W/kg-kHz-Q.

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